CLAIMS

I claim:

- 1. An end-terminal device bandwidth extension system comprising:
- 2 bandwidth extension circuitry for receiving a signal with frequency ≤ 4 KHz and
- 3 providing an output signal including a signal with a narrowband component ≤ 4 KHz and an
- 4 extended component > 4 KHz;
- 5 gain control for controlling the power of the extended signal and the narrowband
- 6 signal; and

- a loudspeaker coupled to the gain control for outputting the output signal.
- 1 2. The end-terminal device bandwidth extension system of claim 1, further comprising a
- 2 microphone and a detector for determining ambient noise from the microphone and for
- 3 providing a signal to the gain control in response to the detection.
- 3. The end-terminal device bandwidth extension system of claim 1, further comprising a
- 2 first voice activity detector that detects the signal and mutes application of the bandwidth
 - extension circuitry during pauses between speech signals in order to not extend spectrum of
- 4 additive background noise.
- 1 4. The end-terminal device bandwidth extension system of claim 3, further comprising a
- 2 second voice activity detector operating on the input signal and sampled faster than 8 KHz is
- 3 used to compute an ambient noise power in the bandwidth extended spectral range.
- 1 5. The end-terminal device bandwidth extension system of claim 1, wherein ambient
- 2 noise power is measured on the input signal to control the level of the extended signal.
- 1 6. The end-terminal device bandwidth extension system of claim 1, further comprising a
- 2 user volume control to control information used in the output gain control.

- 7. The end-terminal device bandwidth extension system of claim 1, further comprising a
- 2 user control over a level of the generated signal in the extended signal relative to the
- 3 narrowband signal.
- 1 8. The end-terminal device bandwidth extension system of claim 1, wherein the input
- 2 signal is up-sampled at a higher sampling frequency by using an interpolation mechanism.
- 9. The end-terminal device bandwidth extension system of claim 1, wherein the input
- 2 signal is delay compensated before applying to the gain control.
- 1 10. The end-terminal device bandwidth extension system of claim 1, wherein the
- 2 bandwidth extension circuitry includes an isolation filter for capturing a part of the spectrum
- 3 in the 0-4 KHz range.
- 1 11. The end-terminal device bandwidth extension system of claim 10, further comprising
- 2 an energy mapping function implemented as a non-linear function and applied to a signal
- 3 output from the isolation filter.
- 1 12. The end-terminal device bandwidth extension system of claim 11, further comprising
- 2 an output filter for capturing a part of a signal output from the energy mapping function in the
- 3 extended frequency range.
- 13. The end-terminal device bandwidth extension system of claim 1, further comprising a
- 2 loudspeaker compensation filter for approximately equalizing a loudspeaker frequency
- 3 response.
- 1 14. The end-terminal device bandwidth extension system of claim 1, wherein the gain
- 2 control combines the input signal and the extended signal so that the output energy is the
- 3 same as the energy of the input signal.
- 15. The end-terminal device bandwidth extension system of claim 1, wherein the gain
- 2 control combines the input signal and the extended signal so that the output energy is equal to
- a level set by a user of the end-terminal device.

- 1 16. The end-terminal device bandwidth extension system of claim 12, wherein the
- 2 isolation filtering, the energy mapping, output filtering and loudspeaker compensation
- 3 filtering are generalized to work in multiple frequency bands.
 - 17. A network device, comprising:
- 2 an input interface;

- a processor that generates a bandwidth extended signal derived from a far-end speech
- 4 communication signal received at the input interface; and
- an output interface to which the bandwidth extended signal is provided.
- 18. The network device of claim 17, further comprising a decoder to decode the far-end
- 2 speech communication signal.
- 1 19. The network device of claim 17, further comprising an encoder to encode the
- 2 bandwidth extended signal.
- 1 20. The network device of claim 18, further comprising an encoder to encode the
- 2 bandwidth extended signal.
- 1 21. The network device of claim 17, wherein the processor is adapted to generate a
- 2 derivative signal having at least one component at a frequency that is outside a bandwidth of
- 3 the far-end speech communication signal, wherein such component is derived from the far-
- 4 end speech communication signal, and wherein the processor comprises a combiner that
- 5 combines the derivative signal with the far-end speech communication signal to generate the
- 6 bandwidth extended signal.
- 1 22. The network device of claim 21, further comprising a gain controller to determine a
- 2 gain for the derivative signal.
- 1 23. The network device of claim 21, further comprising a delay element to add delay to
- 2 the far-end speech communication signal that is combined with the derivative signal to
- 3 generate to the bandwidth extended signal.

- 24. The network device of claim 17, wherein the input interface is adapted to receive a narrowband far-end speech communication signal and the output interface is adapted to provide a wideband bandwidth extended signal.
- 25. The network device of claim 17, wherein the input interface is adapted to receive a narrowband far-end speech communication signal and the output interface is adapted to provide a bandwidth extended signal having a bandwidth that is at least as broad as a wideband signal.
- 26. The network device of claim 17, wherein the input interface is adapted to receive a 4 KHz signal far-end speech communication signal and the output interface is adapted to provide a bandwidth extended signal comprising frequency of > 4 KHz.
- 27. The network device of claim 22, further comprising a voice activity detector to detect whether the far-end speech communication signal contains speech at a given point in time, and wherein the gain for the derivative signal determined by the gain controller differs depending upon whether speech is detected by the voice activity detector.
- 28. The network device of claim 22, further comprising a voice activity detector to determine an interval in the far-end speech communication signal when speech is not present, and wherein the gain controller applies a different level of gain to the derivative signal during the interval as compared to a level of gain applied to the derivative signal prior to the interval.
 - 29. The network device of claim 22, wherein the processor is adapted to determine the gain for the derivative signal by a method comprising the step of determining a level of ambient noise at a near-end of a far-end speech communication represented by the far-end speech communication signal.
- 30. The network device of claim 29, wherein the method further comprises the steps of:
 receiving a near-end signal; and
- determining the level of ambient noise at the near-end by reference to the near-end signal.

- 31. The network device of claim 30, wherein the level of ambient noise at the near-end is not determined by reference to the near-end signal at a given point in time when speech is detected in the near-end signal.
- 32. The network device of claim 30, wherein the level of ambient noise at the near-end is determined by reference to the near-end signal only during an interval when speech is not detected in the near-end signal.
- 33. The network device of claim 17, wherein the processor is adapted to generate a plurality of derivative signals each having at least one component at a frequency that is outside a bandwidth of the far-end speech communication signal, wherein such component is derived from the far-end speech communication signal, and wherein the processor comprises a combiner that combines the derivative signals with the far-end speech communication signal to generate the bandwidth extended signal.
- 34. A network device based method for bandwidth extension, the steps of the method comprising:
- 3 receiving a signal comprising a far-end speech communication;
- generating a bandwidth extended signal derived from the received signal; and providing the bandwidth extended signal to an output of the network device.
- 1 35. The method of claim 34, further comprising the step of decoding the received signal.
- 36. The method of claim 34, further comprising the step of encoding the bandwidth extended signal to provide an encoded bandwidth extended signal at the output of the network device.
- 37. The method of claim 35, further comprising the step of encoding the bandwidth extended signal to provide an encoded bandwidth extended signal at the output of the network device.

- 38. The method of claim 34, wherein the step of generating a bandwidth extended signal comprises the steps of:
- filtering the received signal to generate a first signal having a frequency spectrum that is at least substantially confined to a first band-limited region;
- generating a second signal by mapping at least one frequency component of the first signal to frequency spectrum that is outside the first band-limited region;
- filtering the second signal to generate a third signal having a frequency spectrum that
 is at least substantially confined to a second band-limited region, wherein at least a portion of
 the second band-limited region includes frequency spectrum that is outside the first bandlimited region; and
- 11 combining the third signal with the received signal to generate the bandwidth extended 12 signal.
- 39. The method of claim 38, further comprising the step of sampling the received signal to generate a sampled version of the received signal, and wherein the step of filtering the received signal to generate a first signal comprises the step of filtering the sampled version of the received signal to generate the first signal.
- 40. The method of claim 38, further comprising the step of determining a gain for the third signal.
- 41. The method of claim 38, wherein the received signal that is combined with the third signal to generate the bandwidth extended signal is a delayed received signal, and further comprising the step of delaying the received signal to generate the delayed received signal.
- 42. The method of claim 34, wherein the received signal is a narrowband signal and the bandwidth extended signal is a wideband signal.
- 1 43. The method of claim 34, wherein the received signal is a narrowband signal and the 2 bandwidth extended signal has a bandwidth that is at least as broad as a wideband signal.

- 1 44. The method of claim 34, wherein the received signal is a 4 KHz signal and the
- 2 bandwidth extended signal is a signal comprising frequency of > 4 KHz.
- 1 45. The method of claim 40, further comprising the steps of:
- detecting whether the speech communication contains speech at a given point in time;
- 3 and
- determining a different gain for the gain for the third signal depending upon whether
- 5 speech is detected in the detecting step.
- 46. The method of claim 40, further comprising the steps of:
- determining an interval in the speech communication when speech is not present; and
- applying a different level of gain to the third signal during the interval as compared to
- 4 a level of gain applied to the third signal prior to the interval.
- 1 47. The method of claim 40, further comprising the step of determining the gain for the
- third signal by a method comprising the step of determining a level of ambient noise at a near-
- 3 end of the far-end speech communication.
 - 48. The method of claim 47, further comprising the steps of:
- 2 receiving a near-end signal; and
- determining the level of ambient noise at the near-end by reference to the near-end
- 4 signal.

- 1 49. The method of claim 48, wherein the level of ambient noise at the near-end is not
- 2 determined by reference to the near-end signal at a given point in time when speech is
- 3 detected in the near-end signal.
- 1 50. The method of claim 48, wherein the level of ambient noise at the near-end is
- determined by reference to the near-end signal only during an interval when speech is not
- 3 detected in the near-end signal.

- 51. The method of claim 34, wherein the step of generating a bandwidth extended signal comprises the steps of:
- generating a plurality of derivative signals each having at least one component at a
- 4 frequency that is outside a bandwidth of the received signal, wherein such at least one
- 5 component is derived from the received signal; and
- combining the derivative signals with the received signal to generate the bandwidth extended signal.
- 1 52. A network device based method, the steps comprising:
- 2 receiving an input signal;
- generating an output signal, wherein the output signal represents a wider bandwidth
- 4 version of a speech communication represented by the input signal; and
- 5 providing the output signal to an output of the network device.
- 53. The method of claim 52, further comprising the step of decoding the input signal.
- 1 54. The method of claim 52, further comprising the step of encoding the output signal.
- 1 55. The method of claim 53, further comprising the step of encoding the output signal.
- 56. The method of claim 52, wherein the step of generating an output signal comprises the
- 2 steps of:
- filtering the input signal to generate a first filtered signal having a frequency spectrum
- 4 that is at least substantially confined to a first band-limited region;
- 5 generating a derivative signal having at least one component at a frequency that is
- 6 outside the first band-limited region, wherein such at least one component of the derivative
- 7 signal is derived from at least one characteristic of the first filtered signal;

- filtering the derivative signal to generate a second filtered signal having a frequency
 spectrum that is at least substantially confined to a second band-limited region, wherein at
 least a portion of the second band-limited region includes frequency spectrum that is outside
 the first band-limited region; and
- combining the second filtered signal with the input signal to generate the output signal.
- 57. The method of claim 52, wherein the step of generating an output signal comprises the steps of:
- generating a derivative signal having at least one component at a frequency that is outside a bandwidth of the input signal, wherein such at least one component is derived from the input signal; and
- 6 combining the derivative signal with the input signal to generate the output signal.
- 58. The method of claim 56, further comprising the step of sampling the input signal to generate a sampled version of the input signal, and wherein the step of filtering the input signal to generate a first filtered signal comprises the step of filtering the sampled version of the input signal to generate the first filtered signal.
- 59. The method of claim 57, further comprising the step of determining the gain for the derivative signal.
- 1 60. The method of claim 57, wherein the input signal that is combined with the derivative signal to generate the output signal is a delayed input signal, and further comprising the step of delaying the input signal to generate the delayed input signal.
- 1 61. The method of claim 52, wherein the input signal is a narrowband signal and the output signal is a wideband signal.
- 1 62. The method of claim 52, wherein the input signal is a narrowband signal and the output signal has a bandwidth that is at least as broad as a wideband signal.

- 1 63. The method of claim 52, wherein the input signal is a 4 KHz signal and the output
- 2 signal is a signal comprising frequency of > 4 KHz.
- 1 64. The method of claim 59, further comprising the steps of:
- detecting whether the input signal contains speech at a given point in time; and
- determining a different gain for the gain for the derivative signal depending upon
- 4 whether speech is detected in the detecting step.
- 1 65. The method of claim 59, further comprising the steps of:
- determining an interval in the input signal when speech is not present; and
- applying a different level of gain to the derivative signal during the interval as
- 4 compared to a level of gain applied to the derivative signal prior to the interval.
- 1 66. The method of claim 59, wherein the input signal represents a far-end speech
- 2 communication, and further comprising the step of determining the gain for the derivative
- 3 signal by a method comprising the step of determining a level of ambient noise at a near-end
- 4 of the far-end speech communication.
- 1 67. The method of claim 66, further comprising the steps of:
- 2 receiving a near-end signal; and
- determining the level of ambient noise at the near-end by reference to the near-end
- 4 signal.
- 1 68. The method of claim 67, wherein the level of ambient noise at the near-end is not
- 2 newly determined by reference to the near-end signal at a given point in time when speech is
- 3 detected in the near-end signal.
- 1 69. The method of claim 67, wherein the level of ambient noise at the near-end is newly
- 2 determined by reference to the near-end signal only during an interval when speech is not
- 3 detected in the near-end signal.

- 70. The method of claim 52, wherein the step of generating an output signal comprises the steps of:
- generating a plurality of derivative signals each having at least one component at a frequency that is outside a bandwidth of the input signal, wherein such at least one component
- 5 is derived from the input signal; and
- 6 combining the derivative signals with the input signal to generate the output signal.
- 1 71. A network device based method, the steps comprising:
- 2 receiving an input signal at an input interface of the network device;
- decoding the input signal;

10

- determining an interval in the input signal when speech is not present in the input signal;
- generating a derivative signal having at least one component at a frequency that is

 outside a bandwidth of the input signal, wherein such at least one component is derived from
 the decoded input signal;
 - determining a gain for the derivative signal to generate a gain-determined derivative signal, wherein a lower level of gain is determined for the derivative signal during the interval as compared to a level of gain applied to the derivative signal prior to the interval;
- delaying the decoded input signal to generate a delayed input signal;
- 13 combining the gain-determined derivative signal with the delayed input signal to 14 generate an output signal, wherein the output signal represents a wider bandwidth version of a 15 speech communication represented by the input signal;
- encoding the output signal; and
- providing the encoded output signal to an output interface of the network device.